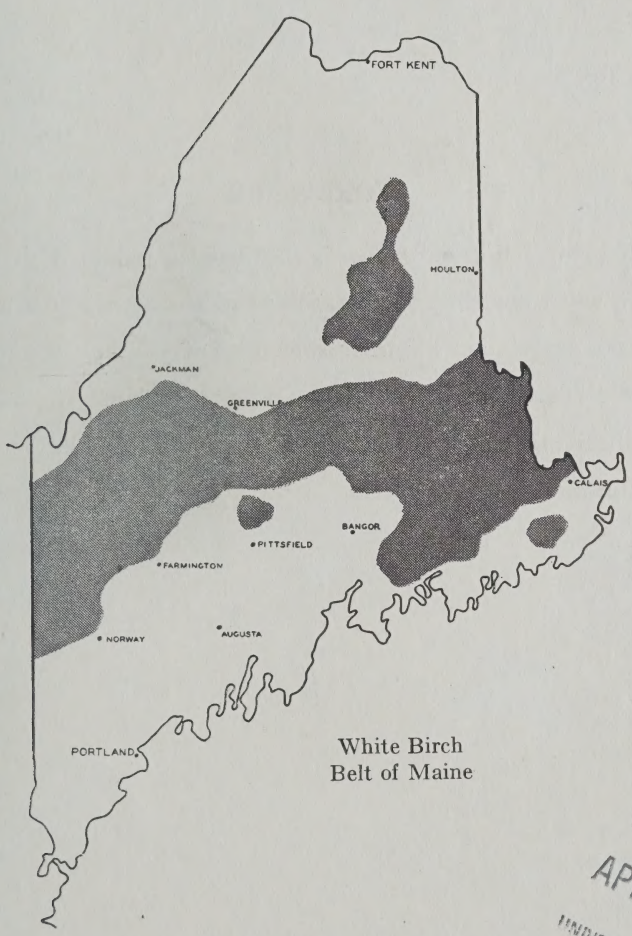
BIOLOGY AND CONTROL
of the
BIRCH LEAF-MINING SAWFLY

By H. B. Peirson and A. E. Brower



White Birch
Belt of Maine

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FOREWORD

The Maine Forest Service is particularly indebted to the hardwood owners and operators, and to the Maine Hardwood Association for their splendid coöperation in aiding the Department in its study and fight against the birch leaf-mining sawfly, and in making funds available for the publishing of these results.

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INTRODUCTION

The birch leaf-mining sawfly appeared in Maine in abundance in 1926 and in epidemic numbers in 1927. During late summer the leaves on whole stands of birch turned dry and brown. For the next six years it seriously injured birch throughout Maine, and it is still abundant in western Maine. Introduced from Europe, this insect had been attacking birch in Nova Scotia for a number of years. The brown, fire-scorched appearance of the birches during August and September led to fear that the trees would be killed. In 1928 an examination showed that white birch was being greatly retarded in its growth. Later the birch mills found that the quality of the wood was being affected. Because the birch has not died over large areas, many people have not realized how extensive the damage has been. The birch owner has suffered the loss of a large percentage of the normal growth of his timber and also a reduction in the quality of the wood. Birch is found practically throughout Maine, and in the broad white birch belt of central Maine it is one of the most valuable trees. These facts led to this study of the biology and control for the insect.

Preliminary investigations by the Maine Forest Service were started at the field laboratory at Bar Harbor where K. A. Salman worked on the problem in the summers of 1927 and 1928. His work was followed by that of R. L. Taylor in 1929 and 1930, and A. E. Brower in 1931 and

1932, with a check on some phases of the problem in 1933, 1934, and 1935. Assistance on the work has been given at times by A. H. Wilkins, A. M. Gillespie, E. C. Hodson, and R. W. Nash. Large numbers of infested leaves have been collected from the widely distributed survey plots, 25,000 to 35,000 each year 1931, 1932, and 1933, and the major portion of the over-wintering cells were cut from these in order to segregate parasites of the sawfly. Smaller numbers have been collected in 1934 and 1935. The life history and growth studies have been time consuming phases of the problem. The authors have made free use of the data and acknowledge the assistance of the others who have worked on the problem. Most of the early experiments were repeated on a larger scale during 1931 and 1932. This bulletin is based wholly upon the results of this investigation in Maine.

HISTORY, CLASSIFICATION AND DISTRIBUTION

The first published report of the birch leaf-mining sawfly in America was in 1909, when MacGillivray described it as a new species. It had been abundant enough to be noticeable in Nova Scotia since 1905, and Hewitt (1911) published the first economic record. It was first noticed in Maine in 1926. In 1927 it was widespread and caused severe browning of the foliage in many sections. It was reported from New Hampshire and the Berkshires in Massachusetts in 1928. In the summer of 1929 it caused noticeable injury to birch in the Adirondack region and severe injury followed in 1930 (Glasgow, 1931). The infestation in Maine is on the decrease in the eastern part of the state where it is oldest, and the birch is apparently recovering and increasing in growth; however a marked increase in infestation occurred in 1934 and 1935 in parts of western Maine.

The insect was originally described from Sweden by Fallen in 1808 as *Hylotoma nemorata*. MacGillivray redescribed it from Nova Scotia in 1909 as *Phlebatrophia mathesoni*. The synonomy is given by Enslin (1914) and Rohwer (1929). It is now known as *Phyllotoma nemorata* Fallen.

In Europe this sawfly is found from Scotland to Sweden and south into Austria. Throughout this wide range no outbreak has ever been recorded. Its natural enemies apparently hold it closely in check. It has been found most abundantly on some of the moors of Austria at an elevation of 2500 to 3000 feet. The life history has not been well known in Europe. It has been confused with other species of sawflies and males have been erroneously recorded. It has also been reported as double brooded.

The distribution in Maine is general and has been heavy throughout the state. Along the coast birch trees growing both near sea level and at over 1500 feet elevation on Cadillac Mountain are very heavily attacked. On Mt. Katahdin the birch is attacked as high up as it grows on the rocky slopes, about 5000 feet elevation. The insect has been collected abundantly flying over the crest of Mt. Katahdin, 5267 feet elevation, above the limit of birch growth. It is found on Little Duck Island four miles from the nearest land which indicates that it depends on wind drift. Experiments have shown that immersion in salt water soon kills the prepupae in their hibernacula, and therefore the insect could not be carried to the islands by ocean drift. On Mt. Katahdin and at Eustis the early frosts have been found to destroy part of the larvae by causing the leaves to fall and dry up before all of the larvae mature. This may help limit the distribution of the insect in northern regions.

ECONOMIC IMPORTANCE

This investigation has been centered upon the injury to white birch. Preliminary studies were made upon the amount of growth during 1928. These examinations showed a marked reduction in the amount of growth (Peirson, Taylor, and Wilkins, 1930). The birch mills found that the wood was being injured and did not turn as well as uninjured wood. The trees also exhibited a tendency to increase the percentage of heart wood. Since heart wood is not used this increases the amount of waste. Therefore, the owners of birch timber have been suffering a double loss from the attack of the insect—a great loss in amount of growth, and a loss in quality of wood.

The birch leaf-mining sawfly has an unusual capacity for a great increase in numbers whenever conditions are favorable. All individuals are females and these deposit fertile eggs. The larval stages live in mines in the leaves and are thereby protected from many enemies. About nine months of each year are spent in a tough waterproof cell, called a hibernaculum, in the fallen leaves. No diseases have been found which regularly attack it. Parasitic insects are important checks upon most of our pests, but this sawfly got to America in some way from Europe and its parasites were left behind in the Old World.

The larva of this sawfly mines between the upper and lower surfaces of a leaf where it feeds on the soft tissue. The injury begins in July. First a tiny raised area in a leaf-tooth shows where the egg was laid. From the leaf-tooth the larva works toward the middle of the leaf making a larger and larger mine. The mined portion soon turns dry and brown. On ornamental trees these brown mines render the trees unsightly, and in the case of both ornamental and forest trees the health

and growth of the trees are injured. Each larva which grows to maturity will consume about 37½ to 40% of an average birch leaf. This figure has been determined after an examination and careful estimate of the mined area in several thousand white birch leaves. The amount of injury must be greater than the actual area consumed because of the drying effect of the continual feeding. Areas of the leaves are often cut off from water by mines and die. Injury is also shown by the yellow or dead margins of the mines. Infested leaves regularly fall two to three weeks earlier than normal leaves. Many leaves have three to six mines in them and as high as twelve have been found. Five hiber-

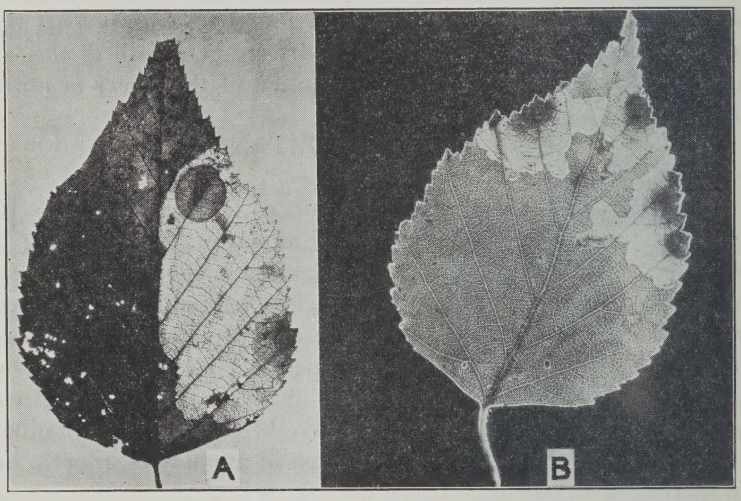

Figure 1. A. Completed mine showing circular hibernaculum.
B. Partial mines showing larvae mining.

nacula have been found many times. Such leaves are completely mined out. Individual trees have been examined which had an average infestation of 238.4%, or over two and one-third mines for every leaf.

So far as is known no trees have been directly killed by the attacks of this sawfly. An increase in the number of dead branches and tops has been noticeable. All of this weakens the trees and leads to a greater amount of injury by other birch insects, and diseases, some of which kill the trees. The heaviest injury comes during the late summer and so does not appreciably affect the amount of growth that year. However, the growth of the following year is reduced proportionately to the amount of injury and vigor of the trees. Trees when injured usually require more than one year to recover and make normal growth. The tables and graph which give results of this study indicate that the growth

has been but little affected for one or two years after the injury began, and that the retardation in growth continues for a number of years after the insect injury to the leaves becomes unimportant.

Observation plots were selected in 1929 for a study of the effect of the insect upon white birch. Twenty quarter-acre plots distributed throughout the white birch belt were laid out in stands of good birch timber. Some plots have been cut but others have been established to take their places. Starting in 1929 these have been visited at least once each year. Each fall all plots have been visited, counts have been made of the percentage of injured leaves, and increment cores have been secured to determine the amount of growth. This annual fall examination of all plots has been designated a "survey." The surveys were made immediately after the leaves fell. A representative sample of the fallen leaves was taken at several places on each plot; these were thoroughly mixed and five hundred leaves counted out. This lot of five hundred leaves was subcounted to obtain: the percentage of leaves infested, the number of mines in each leaf, the number of prepupae present and missing from the hibernacula, and other data. Most mines are conspicuous, and the presence or absence of hibernacula and larvae is easily determined. Tables 1 and 2 give the results of these annual surveys of the birch plots.

The birch leaf-mining sawfly became destructive in Nova Scotia, where it was first reported on this continent, before it did in Maine. Presumably it entered southeastern Maine from New Brunswick and gradually spread westward through the state. As it increased in numbers it produced greater and greater injury to the birch trees, which is shown by a continued retardation in growth. Along with heavy infestation goes an increased number of mines per leaf which increases the injury. At the time the infestation and growth studies recorded in Tables 1 and 2 were started the insect had apparently passed its greatest abundance at places in southeastern Maine, but it was very abundant through most of the state and increasing in the western portion. This is shown by the yearly infestation figures in Table 1. The percentage of retardation will pass through the same cycle as the infestation but will lag behind and show up longer because injured trees are slow to recover their normal growth. An insect, like the sawfly, which injures the leaves during the latter part of the season does not appreciably reduce the growth that season, but does affect the amount of growth during the following season. By taking sections of the tree or cores with a specially designed auger the rings can be counted and measured and the amount of growth of each tree determined. In this study cores were taken with an increment borer, the growth rings were stained whenever necessary, and the material examined and measured under a

binocular microscope. Figures on birch growth show that the white birch of Maine has suffered an average annual loss of over 20% for the five year period 1928-1932. This is a great tax on birch owners which many of them do not fully realize.

TABLE 1

Summary of Sawfly Infestation on Birch Plots; Counts on Sample of 500 Fallen Leaves

	Percentage of Leaves Infested							Total Number of Mines in 500 Leaves				
	1929	1930	1931	1932	1933	1934	1935	1931	1932	1933	1934	1935
Area of Oldest Infestation												
Indian Town	25.9	8.2	4.0	3.2	0.2	0.4	0.0	20	16	1	2	0
Topsfield	37.9	30.6	17.8	5.6	0.6	0.6	0.2	103	30	3	3	1
Danforth	39.0	31.0	28.0	6.4	1.0	0.2	1.0	157	35	5	1	5
Cherryfield	16.2	10.2	12.6	9.2	1.4	1.4	1.2	66	52	8	8	6
Heavily Infested Plots												
Hersey	25.3	29.0	36.2	11.0	0.8	2.8	3.8	236	63	4	14	25
Nicatous Lake	60.2	25.8	18.0	11.2	1.6	0.2	0.4	103	58	8	1	2
Aurora			14.6	10.8	2.2	2.4	3.4	84	60	11	13	17
Hartland			15.6	17.4	3.8	1.0	2.2	82	91	20	5	11
Bowerbank	50.6	11.2	27.4	29.6	4.6	2.2	2.6	162	190	25	11	13
Caratunk	23.4	43.4	52.2	18.0	2.8	3.0	13.8	381	108	15	15	83
West Forks	34.2	40.02	49.0	26.4	5.0	3.2	44.0	378	155	26	18	334
Freeman	42.2	20.02	38.4	30.4	2.4	0.8	6.4	214	200	12	4	35
Strong	39.6	31.0	53.2	50.6	23.4	27.4	19.8	375	339	145	160	116
Dallas	23.5	39.2	68.0	47.8	14.8	16.6	14.4	563	318	87	95	101
West Bethel	39.8	32.4	41.64	15.0	18.0	26.0	37.4	244	87	101	157	250
Woodstock	32.1	30.02	38.8	49.0	29.2	16.0	6.6	249	353	185	92	37
Lightly or more recently Infested Plots												
Masardis	19.8	9.8	22.0	7.2	1.6	2.6	3.2	127	40	8	13	17
Jim Pond	33.4	38.8	57.0	42.0	11.4	45.6	57.4	489	291	59	349	552
Grafton Notch	32.0	21.0	8.98	7.8	7.2	18.8	14.8	49	42	42	110	85

Table 2 shows the amount of this loss to birch growth for the five years after 1927 compared with the previous five years. The plots have been grouped to show more clearly the effect of continued attack by the sawfly. Its westward and northward spread across the state is indicated by the low retardation on the plots farthest from Nova Scotia,

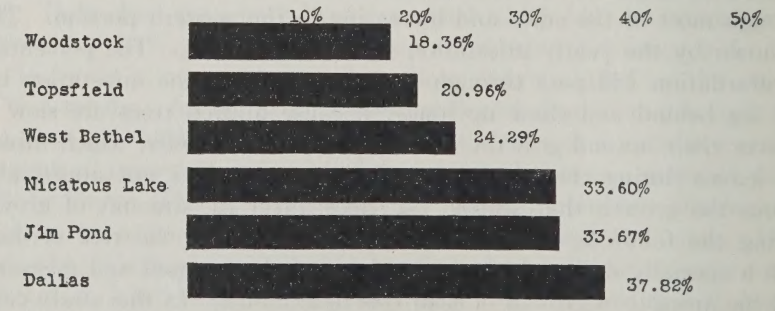

Figure 2. Average annual retardation in birch growth during the seven years, 1928-1934, compared with the previous ten years, 1918-1927.

as shown in this table. The infestation showed an increase in 1934 and 1935 on some of these plots in western Maine. That this loss shown in Table 2 was not due to unfavorable growing seasons is indicated by the good or increased growth which was made at Masardis and other plots

TABLE 2

Showing Relation between Amount of Infestation and Amount of Annual Retardation in White Birch Growth

	Average percentage of leaves infested for three years 1929-1931 *	Average growth in inches for five years †		Average percentage of retardation for five years 1928-1932
		1923-27	1928-32	
First Infested Plots—Infestation Decreasing—Growth Recovering				
Indian Town	12.70	.0429	.0422	1.63
Topsfield	28.77	.0480	.0410	14.58
Danforth	32.67	.0379	.0368	2.90
Cherryfield	13.00	.0436	.0390	10.55
Average	21.78	.0431	.0398	7.77
Heavily Infested Plots—High Retardation in Growth				
Hersey	30.17	.0533	.0396	25.70
Nicatous Lake	34.67	.0456	.0360	21.05
Aurora	High	.0501	.0376	24.95
Bowerbank	29.73	.0606	.0540	10.89
Caratunk	39.67	.0481	.0282	41.37
West Forks	41.13	.0425	.0256	39.76
Freeman	33.60	.0692	.0496	28.32
Strong	41.27	.0861	.0630	26.83
Dallas	43.57	.0486	.0404	16.87
West Bethel	37.93	.0279	.0236	15.41
Woodstock	33.70	.0463	.0326	29.59
Average	36.54	.0526	.0391	25.61
Recently or Lightly Infested Plots				
Masardis	17.20	.0235	.0272	—15.74‡
Jim Pond	43.07	.0600	.0548	8.67
Grafton Notch	20.67	.0550	.0504	8.36
Average	26.98	.0462	.0441	4.404

*Injury by this sawfly comes late in the summer and its effect is shown on the next season's growth; therefore the 1932 infestation is not included.

†Represents the annual growth of an average of fifteen trees on each plot.

‡This plot showed an increase of 15.74% instead of retardation and this figure must be subtracted from the others to average retardation.

which had not been severely injured; moreover an examination of the ring growth of other hardwood trees on the same plots showed that they made a normal or slightly more than normal growth for the period 1928-1932. Figure 2, the graphic representation of average growth and loss in average growth on six birch plots since 1917, shows that white birch growth has been greatly retarded in the years following heavy sawfly infestation. A comparison of the graph with Table 2 shows that the average amount of retardation on the plots in western Maine has increased since 1932. The percentages of loss in growth shown in Table 2 and Figure 2 should be considered in connection with the percentages of infestation given in Table 1, remembering that the effects of defoliation by this insect do not affect the growth until the following year and that this retarding effect lasts for several years.

OTHER BIRCH INSECTS

Other birch insects cause injury which is often confused with that of the birch leaf-mining sawfly. *Fenusa pumila*, another sawfly, causes the most similar injury but attacks succulent, immature, or terminal leaves; especially on sprout or sucker growth. The mined leaves have a wrinkled, scalded appearance; more than one larva is present in each mine; and the frass is left in the mines. The birch case bearer, *Coleophora salmani*, in its early larval state makes tiny mines, and later when in its case eats a little hole through the epidermis from which it eats out the tissue as far as it can reach. The presence of a larval case or small mines with a hole in one epidermis will identify the injury as that of this or one of the two other rarer case bearers on birch. The larva of a rare moth, *Eriocrania* sp., makes a very similar mine, but in immature leaves, and leaves serpentine frass threads in the mine. This larva is maggot-like and not flattened. The birch leaf skeletonizer, *Bucculatrix canadensisella*, produces widespread injury which is often confused with that of the sawfly. The tiny caterpillars of the skeletonizer eat very small holes from the underside into the green substance of the leaves. Often so many of these tiny holes are eaten that the leaves turn dry and brown over great areas giving the birch growth a fire-scorched appearance in late August and September. No noticeable mines are formed and if the trees are shaken the slender greenish caterpillars will spin down on silken threads.

HOST PLANTS

The birch leaf-mining sawfly is practically restricted to the birches for food plants, but is known to attack alder and hazelnut. Gray birch, *Betula populifolia*; white birch, *B. papyrifera*; and the varieties of the white birch are all heavily attacked. The variety *cordifolia* is found severely infested above 4000 feet elevation on the sides of Mt. Katahdin. The ornamental varieties of the European *B. alba* may be severely injured. Two ornamental red birches, *Betula nigra*, at Bar Harbor have been rather heavily attacked. Yellow birch, *B. lutea*, is very lightly infested. Mature larvae are rarely found in yellow birch leaves. *Betula coerulea grandis* in Aroostook county was found lightly infested in 1933. No infestation on black birch, *B. lenta*, has been found. This species extends northward only into southwestern Maine, where the sawfly is scarce and opportunity for examination has been limited. The alpine species *B. glandulosa* which grows on the Northwest Plateau of Mt. Katahdin was very lightly infested in 1933. Bog birch, *B. pumila*, was examined in 1933 on Crystal Bog in Crystal under conditions very unfavorable to the sawfly and no infestation was found. Larvae have

been found in the field mining in *Corylus rostrata* and *Alnus* sps. during two seasons. None have been observed to mature in Corylus. Most of those found in Alnus have failed to mature, but in 1934 a bush of *Alnus crispa mollis* was found with several larvae in the leaves; a few of which matured, pupated, and emerged normally.

The following species of trees and shrubs have been caged with this sawfly, in large wire screened cages in the field, to test forced oviposition: shadbush, *Amelanchier* sp.; hop hornbeam, *Ostrya virginiana*; alder, *Alnus* sps.; poplar, *Populus grandidentata* and *P. tremuloides*; beaked hazelnut, *Corylus rostrata*, and witch hazel, *Hamamelis virginiana*. One hundred or more sawflies were introduced over several days time into each of the cages. Oviposition was fairly heavy on beaked hazelnut; 193 larvae developed on a few caged bushes. None of these larvae on hazel developed further than the third or fourth instar. Adults caged on black birch in 1933 failed to oviposit. Similar experiments on bog birch in 1934 resulted in oviposition and normal mines, though no larvae matured. During 1929 and 1930 batches of sawflies in lamp chimneys were caged on the above species, except black and bog birches, and also on red maple, *Acer rubrum*; willow, *Salix* sp.; beech, *Fagus grandifolia*; cherry, *Prunus* sp.; and red oak, *Quercus borealis*. A few eggs were laid on alder, shadbush, hop hornbeam, and poplar; but few hatched and all of these larvae died without appreciable mining.

Description of the Stages

DESCRIPTION OF THE STAGES

The Adult. This sawfly is a small, black-looking insect about the size of a housefly but appears narrower. It is about one-fourth inch long, black in color, with fine pale yellow or whitish markings on the head, thorax, legs, and edges of the upper side of the abdomen. The wings are transparent with a stigma or black area in the front margin of the fore wings. All are females; no males are known.

The Egg. The egg is ovoid, flattened dorsoventrally, flabby, enclosed by a smooth membrane, watery white or the color of egg-white. Freshly deposited eggs averaged 0.308 x 0.531 mm., swelling occurs with development.

*The Larva.** First Instar.—Length .8 to 1.8 millimeters, markedly buprestoid in shape, and watery white to cream in color. The smooth, flattened, pale brown head is wider than long and strongly retractile, with forward projecting darker brown jaws and black eyes. The dorsoventrally flattened body has ten abdominal segments (probably an indistinct eleventh is present) with the anal end rounded. Thoracic legs fleshy, without claws, projecting laterally, weak and functionless. The basal portions of the prothoracic legs are modified into eversible aids to locomotion. The prothorax and first eight abdominal segments each bears a pair of spiracles. A few lateral setae are present on each segment. The skin is finely pitted. The food tract is usually plainly seen.

Second Instar.—Length 1.2 to 2.6 millimeters. This stage differs from the first only in degree: the shape is less buprestoid; the colors become deeper; the prothoracic legs become set off by the chitinization of the surrounding ventral surface; a divided, prothoracic cervical shield becomes prominent; and the last segment developes more fully the prominent apical chitinization ventrally and laterally, which is important in movement. This last consists of a very coarsely serrate, strongly chitinized margin supported by a roughened or spinous belt, and behind it eversible tissue. Fleshy probuterances or uropods become more evident on abdominal segments two to eight inclusive. The front becomes demarcated, because paler.

*Head-capsule sizes are given in Table 4.

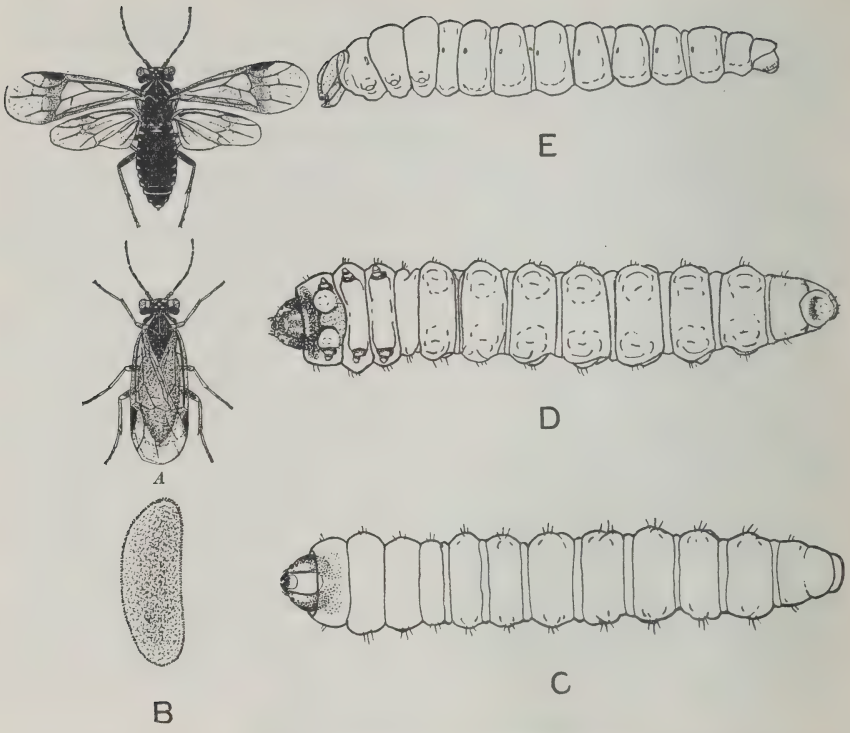

Figure 3. A, Adults (4X); B, Egg (30X); C and D, Dorsal and ventral views of larva (8X); E, Lateral view of prepupa (8X)

Third Instar.—Length 2 to 4 millimeters. Second stage structures continue to develop.

Fourth Instar.—Length 2.6 to 5.3 millimeters, otherwise similar to preceding except that chitinous areas have become darker brown.

Fifth Instar.—Length 4.8 to 7.4 millimeters. Similar to last, except a tendency to all chitinous parts but the head to become paler.

Sixth Instar.—Length 6.5 to 10 millimeters. Similar to preceding stages, except modification in chitinization: the sides of the head, margins of the vertex, and a narrow transverse area before the prothoracic legs darker; other chitinous parts becoming paler, especially the cervical shield. The thorax is somewhat flattened and sloping forward, but the adbomen has become nearly round. The heart is evident as a narrow, darker, dorsal band.

Seventh Instar or Prepupa.—Length 6 to 8.8 millimeters, the head showing but a slight increase in size; a non-feeding, hibernaculum-forming, over-wintering stage; greatly changed from preceding stages; appearing broader and flatter, especially below, and shrunken. White or creamy white, except black eyes, and dark brown chitinous margins on lips, bases and blades of mandibles. The head has changed from a horizontal position to a more vertical one; and the broad, heavy, shearing mandibles have become pointed and prong-like in shape. Internally, the silk glands have developed greatly.

The Pupa. The pupa is about 6 millimeters in length. The appendages are encased separately and are not closely pressed to the body. It is entirely white in color, but color soon appears in the eyes and ocelli and a little later in the mouthparts. The black colors of the adult partly develop before emergence from the pupa.

LIFE HISTORY AND HABITS

Due to the scarcity of the birch leaf-mining sawfly in Europe the life-history has not been well-known. It has been confused with other species and conflicting statements regarding its life have resulted. The following account of the life-history and habits is based entirely on the results of this study in Maine.

The Egg

To the unaided eye the position of an egg in the leaf is shown by a very small bulge in the leaf tooth. The leaf tissue shrinks about it, often becoming brownish. The egg gradually swells as hatching time approaches; therefore its position is most easily seen just before hatching. As hatching time approaches the outline of the developing larva can be plainly seen. The venter is upward, and the caudal portion doubles back in the egg on the side away from the leaf-margin. The eyes are plainly seen as a pair of black spots. Three lots of twenty-five eggs each were measured to determine the size and the increase in size. One day old eggs averaged 0.308 x 0.531 millimeters. Fourteen to fifteen day old eggs measured 0.440 x 0.616 millimeters. Eggs nearly ready to hatch measured 0.442 x 0.630 millimeters. The latter showed an increase over the one day old eggs of 43.5 per cent in width and 18.7 per cent in length. The disproportionate increase in width seems to be due to the position of the developing embryo. The incubation period of 158 eggs in 1931 averaged 19.6 days, ranging from 12 to 26 days. In 1932 the incubation period of 1120 eggs averaged 19.0 days, ranging from 16 to 26 days. Observation and experiments show that about one day elapses between hatching and evident feeding, and so one day was subtracted from all records of the time between oviposition and first evident feeding in order to secure the incubation period. Practically all eggs hatch within a five day period centered on the average, weather conditions accounting for part of the variation.

The Larva

The newly-hatched larva is a soft, flattened, tapering grub with a broad, flat thorax. It is about the color of the white of an egg with a broad, brownish head and darker brown jaws. By the time it becomes mature the body has become firm, white or slightly yellowish white, with a darker head and dark brown jaws. If a larva is removed from the leaf, it will appear nearly legless with the head partly enclosed by the enlarged thoracic segments. By holding the leaves to the light the larvae can be easily seen in their mines. From five to ten weeks are required for the larvae to reach maturity. Larvae develop faster in gray birch than in white birch.

The larvae are helpless outside of their mines, the legs being useless for movement. They move between the two surfaces of the leaf, which enclose the mine, somewhat like a worm in its burrow, aided by eversible, ventral aids to locomotion on the thorax and posterior end, and a spinous area on the underside of the last segment. The spiny or roughened ventral tip of the last segment prevents slipping backward while moving or feeding, the head and fore part is retractile and extensile, and the eversible areas can be swollen outward to press against the mine or withdrawn; these enable the larvae to move readily in the mines. The legs project laterally and are useless. The larvae are always upside down or with the venter upward in the leaves. On the tree the leaves droop and resting larvae usually lie in the mines with head higher than the posterior end.

The larva molts when its skin gets too small. The larval skin splits along the back of the thorax and the head capsule opens, than the larva pulls its head free and works the old skin off behind. These cast skins are apparently regularly pushed from the mines. The larvae open one or more holes along the margin of the leaf out of which the skins and frass are pushed or else shaken by the wind. The first opening is often in the apical margin of the leaf-tooth in which the egg was placed, opposite the egg-slit. The leaves usually droop and gravity is utilized in helping clear the mines which are usually fairly free from excrement. The larvae make a peculiar rasping or rustling sound by swinging the posterior portion of the body in an arc with the chitinous area on the last segment rasping across the more or less dry leaf tissue which encloses the mine. At times under trees containing many nearly mature larvae, this sound may be heard almost continuously.

Some difficulty was experienced in determining the interval between hatching and first feeding. Only individuals found, upon dissection of egg-pocket, pushing off the eggshell could be considered, and only rarely was it possible to prevent drying and keep the proper pressure of the leaf tissue on the larvae, necessary in order to secure normal feeding. In the four successful cases, the prefeeding time ranged from 17 to 19 hours, averaging 17.75 hours. The eggshell is merely a thin membrane when the developing larva ruptures it. This membrane is either pushed off behind the larva into the lower portion of the egg-pocket or is simply left behind as the larva feeds.

The young larvae are especially dependent on a normal mine, and the molts cannot be seen through the leaf. Larvae can be reared in the laboratory by the following method: gather suitable mines in the field each day and remove the larvae from them, then transfer the larvae in the laboratory into the mines in these fresh leaves. A few examples were reared through all instars by this method. The material was kept humid in glass containers.

Table 3 gives the length of the instars from both field and laboratory data. Trees were caged in the field, with large numbers of sawflies enclosed for one day. The cages were removed after hatching began, and surplus eggs and larvae were destroyed. The twenty-nine field records on the length of the first instar were secured by finding them molting on dissecting a large number of mines of first instar larvae of recorded age. Almost all of the second instar records were secured by subtracting the average length of the first instar from the average length of the first two instars. The second molt could be seen in some mines, and later molts could usually be detected. The field larvae, which were removed from the trees, changed their status from field to laboratory

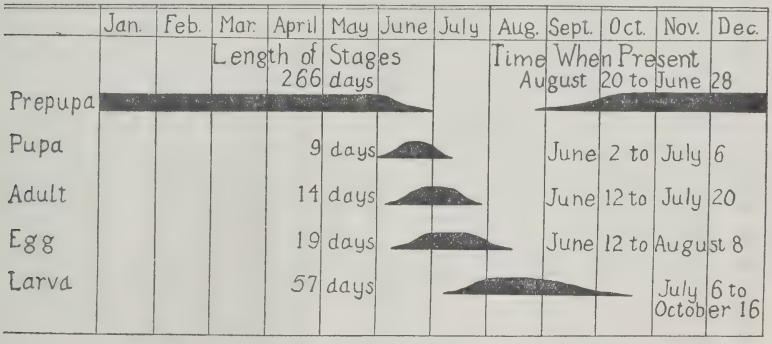

Figure 4. Life history of birch leaf-mining sawfly and time when the different stages may be found.

records two days after the leaf was picked. Observation showed that activity would be about normal for at least that long. As is shown in Table 4, measurements of living larval-heads consistently averaged lower than dissected heads; this was due to the difficulty of getting the strongly retractile head extruded and level without injury. Measurements upon the same individuals gave a small though consistent increase in head size of the prepupa over the sixth instar.

A few anomalous cases in development were found. The larval development is faster in gray birch than in white. Two or three individuals matured in five instars in white birch; one required 47 days, another 55 days, and the somewhat doubtful third case developed in 58 days. These cases show both faster development and maturity with one less molt under some conditions. On the other hand, one individual required 72 days and seven feeding instars to complete its development.

TABLE 3
Length in Days of Instars of Birch Leaf-Mining Sawfly

NOTE.—Tabulation of the data from 246 larvae giving usable records, out of those hatching from 1120 charted eggs. Field records became laboratory records after removal of leaf from tree.

	1st Instar		2nd Instar		3rd Instar		4th Instar		5th Instar		6th Instar		Time to form Hibernaculum	Egg to Hibernaculum	
	in field	in lab.	in field	in lab.	in field	in lab.	in field	in lab.	in field	in lab.	in field	in lab.		in field	in lab.*
No. of cases	29	25	63	22	19	27	42	60	31	57	24	54	140	42	98
Min. length	11	10	†	†	4	4	4	4	4	3	13	12	0.5	39	37
Max. length	24	22	†	†	8	12	8	12	12	9	24	19	6	71	67
Average Days	14.207	14.4	9.342	5.954	6.316	6.296	5.809	5.717	7.161	6.193	19.125	14.63	1.586	57.952	51.269

*Brought in from the field at various stages of development.
†Length of second instar obtained by subtracting average of the first instar from average of the first plus the second; see discussion of methods.

TABLE 4
Size of Head of Birch Leaf-Mining Sawfly

Measurements of Living Larvae under Cover-Slip and of Dissected Larval Heads in Millimeters*

	1st Instar		2nd Instar		3rd Instar		4th Instar		5th Instar		6th Instar		Prepupa†
	Living	Dissected	Living	Dissected	Living	Dissected	Living	Dissected	Living	Dissected	Living	Dissected	Dissected
No. of Cases	4	170	22	104	61	26	65	60	67	11	63	10	138
Min. Size	.3809	.3483	.4354	.4462	.5333	.5442	.6521	.6421	.7945	.8054	.9350	1.0013	.9687
Max. Size	.4027	.4462	.4789	.5007	.6095	.6530	.7945	.9034	.9469	1.0013	1.0884	1.0884	1.1754
Average	.3918	.3954	.4680	.4806	.5834	.6128	.7317	.7713	.8696	.8826	1.0158	1.0448	1.0797

*Measurements were made with an ocular micrometer (each unit 0.043535 mm.) in a binocular microscope and converted into millimeters.
†Each individual was dissected after the hibernaculum was formed.

The Prepupa

The molt into the prepupal stage takes place a day or more before the hibernaculum is started, the molted skin being left free in the mine. The prepupa forms its hibernaculum any place in the mine where the surfaces are intact but prefers the central portion of the leaf. The lens-shaped hibernaculum is formed of silk-like material from the large silk glands. The prepupa turns about as it works, and the silk exudes as a gluey material from an opening in the lower lip. This material hardens into a tough parchment-like substance, and the prepupa working inside the cell forms around itself the hibernaculum. The bottom and top of the cell and any foreign objects are glazed over with the silk. When the hibernaculum is completed the prepupa has a roomy, waterproof cell in which it remains until the following June. The hibernaculum is generally roughly circular, but ovoid and irregularly shaped hibernacula are not uncommon. The time required to form the hibernaculum varies greatly with the weather. Individuals were observed to spend from one-half to six days, averaging 1.58 days for 140 individuals. The hibernacula are easily seen in the fallen leaves, and by holding the leaf to the light the prepupa can usually be seen inside of the cell. The hibernacula occasionally become partly or completely separated from the leaf in which they are formed. No evidence has been found that the prepupa cuts its hibernaculum more or less free as reported in Europe.

The Pupa

The pupal period, which occurs during June and July, is little in evidence as it is passed in the hibernacula in leaves on the ground. It lasts only about eight or nine days, averaging 8.83 days in forty-eight cases with a range from six to twelve days. This time is required for the soft parts to develop, harden, and acquire part of the adult coloration. The old hibernaculum or pupal cell which remains in the leaf is tough and decay-resistant and persists after most of the leaf has decayed.

The Adult

The adult emerges from the pupal case by splitting the pupal shell down the back of the thorax. It slowly crawls through the opening, pushing the empty shell off behind. Until the soft covering and wings have hardened and the adult coloration has been attained, the insect is not very active. This period ranges from one-half to four days, averaging 1.82 days for forty-eight individuals observed. When ready to emerge the sawfly cuts a neat circular hole near the middle of the hibernaculum through which it comes forth. With many of the exit holes

the circular piece which is cut out remains attached by a narrow strip and is turned back like a flap. Several holes may be partly cut before the insect emerges. Under cage conditions these emergence holes are cut apparently to the same extent in either the upper or the lower side as the leaf lies on the ground. The sawflies crawl out between the overlying leaves or pierce them if necessary in order to reach the sunlight. Infested leaves tend both to fall first and to collect in hollows where they are covered over. Immediately after emergence or in a short time one or two small drops of pinkish white fluid are voided. Most individuals emerge during the heat of the day.

Emerging sawflies have been found at Bar Harbor from June 8 until July 8, with the height during the last ten days in June. Small numbers appear before and after these dates. The scant information at hand indicates that emergence is a week or ten days later in the northern portion of the birch belt. Weather conditions hasten or delay emergence. The sawflies appear to live from eight to fourteen days or longer. They live the longest during prolonged cool spells of weather.

Soon after the sawfly comes out into the sunlight it is strong enough to fly to the nearby branches of trees. The first hours in the trees are spent walking about on the leaves or in short flights. Completely parthenogenetic, this sawfly, unlike most insects, does not even have to wait for a mate before beginning to lay its eggs. Eggs of some insects are never fertilized and develop without it. No males have been found of this sawfly, though thousands of specimens have been examined over a period of years. Part of the eggs are fully developed when the adult emerges, and many individuals begin oviposition within a few hours after they fly to the foliage.

Egg laying appears to be the only serious work which the sawflies have to perform. Leaves in both sun and shade may be heavily attacked, but heavily shaded leaves are avoided. Diseased, insect eaten, honey dew covered, and partly grown leaves are avoided for egg laying. They rarely oviposit in a leaf-tooth already containing an egg, and usually they fly to another leaf as soon as an egg has been deposited. Mature leaves exposed to light and air are much more heavily attacked than nearby leaves. Leaves containing ten or more eggs have been found, but in such cases a large percentage of the eggs and young larvae die. Most leaves will provide food for two or three larvae. Many cases of four and five larvae reaching maturity in a single leaf have been seen. In 1931, with an average infestation for the state of 31.75 per cent, 5.27 per cent of the leaves had more than two evident mines in them.

The sawfly has an interesting instrument with which it makes pockets in the leaves for its eggs. By looking at the insect a pair of flattened plates may be seen near the end of the underside of the abdomen. Be-

tween these outer plates two thin, broad, pointed blades glide over one another. Their lower edges bear a row of big teeth. These saw-like tools are used to cut the slit in the leaf and form the egg-pocket, and they give to these insects their common name of sawflies.

The eggs are invariably deposited in a leaf-tooth. Leaf teeth along the median and apical portion of the leaf are usually selected, with small numbers toward the base and in the elongate tip. After walking about over the leaf and touching it with her antennae until satisfied that it is suitable for her purpose, the sawfly selects a leaf-tooth in which to deposit an egg. She faces the petiole or the basal portion of the leaf, bends

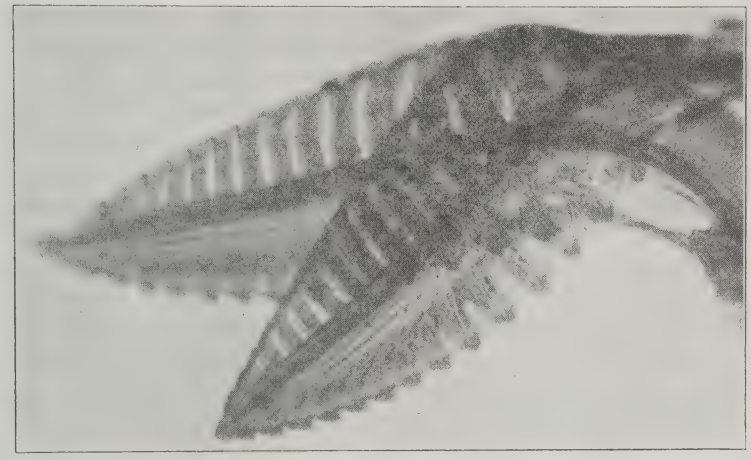

Figure 5. Saw-like ovipositor (133X).

and turns the abdomen into position to cut the rounded margin and form the egg-pocket. The sawfly rests on the upper surface of the leaf while making the egg-pocket, but the hind leg, and rarely the middle leg, nearest the margin may reach over the leaf-margin and grasp the underside of the leaf. The egg-slit is cut near the margin in the leaf-tooth on the basal edge, or the side nearest the leaf stem. In the field eggs are rarely inserted in the apical margin of the leaf-tooth. On caged trees where eggs were very crowded, 500 oviposition slits were examined. Of these 97 per cent were on the basal side of the leaf-tooth and the rest on the apical side.

The eggs are inserted in the leaf-tissue between the upper and lower surfaces of the leaf-tooth. With her saw-like ovipositor the sawfly cuts a slit very near the margin on the upper side of the leaf, and hollows out a pocket in the mesophyll of the leaf. This egg-pocket is worked out far enough back from the margin so that the deposited egg will be

back a short distance from the slit made in the upper epidermis of the leaf. The time required to cut the egg-slit, form the egg-pocket, and place the egg is from one-half to one and one-half minutes, averaging slightly over one minute in a number of cases which were timed. The sawflies make many abortive attempts at oviposition. Egg-slits are cut and even egg-pockets are formed and abandoned. Egg laying begins as soon in the morning as the temperature reaches 65 to 70° F. in the shade. The heaviest oviposition seems to be from ten to twelve o'clock If the afternoon sun is too warm, they seek shady places to oviposit. Oviposition has been observed to cease when the temperature in the shade exceeded 85° F. In a valley, oviposition was observed until after sunset on one warm evening. Forty individuals, for which records seem satisfactory, deposited from twenty-two to sixty-seven eggs, or an average of 33.9 eggs. This is the combined result obtained by three workers during four different years. The average sized female contains a much larger number than this of developed eggs, and also a number of undeveloped eggs. Dissection of twenty-five freshly emerged medium-sized females gave an average of 65.5 developed and 24.4 undeveloped eggs. Another lot of one hundred females, taken at random from preserved material, contained an average of 54.4 developed eggs per female. Some of the eggs which are undeveloped at time of emergence continue to develop. Dissection of caged females which had deposited a number of eggs shows that a part of the undeveloped eggs continue to develop while others disintegrate. Eight medium-sized females which deposited an average of 33.6 eggs were then dissected and found to contain an average of 39.8 developed eggs (a total average of 73.4 developed eggs), and an average of 11.9 undeveloped eggs. This is an increase of 12.06 per cent in developed eggs, and a decrease in the undeveloped eggs of both those which develop and those which disintegrate, compared with the freshly emerged females. Small females contain fewer eggs. Twenty-five small females contained an average of 15.6 developed and 12.0 undeveloped eggs. Compared with medium-sized females, these contained only 23.82 per cent of developed eggs and 49.18 per cent of undeveloped eggs. Some dwarfed individuals have been found to be completely sterile. Large females were found to contain more eggs than the average individual.

When the sawfly emerges, its abdomen is distended with eggs. The sawfly has two ovaries, each of which has eight to fourteen egg tubules, usually eight, on each side. Each tubule usually contains three or four mature ova and two to five immature ova. In the case of the very small ova, apparently the alternate ones disintegrate. The egg calyxes are large and unite in their posterior portion.

The number of eggs deposited per day varies greatly with weather conditions. Caged females usually deposited some eggs the first day, with the heaviest oviposition on the third or fourth days. From none to twenty-six eggs in one day were secured from caged individuals. Several deposited over fifteen eggs during a twenty-four hour period, and a few over twenty. Egg laying continues for about one week, though some sawflies live for at least ten to fourteen days and may continue to lay eggs.

By far the heaviest infestations observed have been on birches scattered among conifers along the ocean shore. Some of the trees on headlands become brown with hundreds of the unsightly blotch mines. Trees on which every leaf and developed mine have been counted have shown as high as 2.38 developed mines per leaf, or an infestation of 238.4 per cent. The initial infestation in terms of average eggs per leaf must have been several hundred per cent. On mountain tops the infestation is often extremely high. This is apparently due to movement with air currents.

The flight is weak with rapid beating of the wings. Flight is with the wind, as they cannot breast a light wind. When a wind is blowing they keep in sheltered situations or drift with the wind. This proneness to drift with the wind and to be borne by air currents would account for the heavy infestation found on islands off the Maine coast, for the numbers taken on the barren, rocky summits of Mt. Katahdin, and for those found washed up on the seashore. The adults spend the greater part of their time either resting quietly on the leaves or walking over them at which time the antennae are often waved about and touched to the leaf surface. The sawfly is most active on warm sunny mornings. Temperatures from 65 to 80 or 85° F. are preferred. On cool or rainy days they sluggishly cling to the upper or under side of the foliage. Hot afternoons are spent resting in the shade. Entire lots of them died in wire screened oviposition cages in the sun on hot days. They are not found near the ground in thick birch growth though the tops become heavily infested.

The senses appear to be poorly developed. When approached closely the insects fly or drop to the ground. A stick may sometimes be slowly moved near until it touches the face before the insect becomes aware of its presence. When touched on the back they feign death. The sense of smell is so poorly developed that the insects found on leaves in the field sometimes ran headlong into drops of strongly odoriferous mixtures when baits were being experimented with. Some strong smelling essential oils were detected before contact with them. Many experiments with two types of olfactometers demonstrated only that the sawflies are strongly phototropic. The pungent odors of evergreens in

the field are not repulsive to them. Sawflies have been seen resting on spruce, arbor vitae, and pine twigs.

A number of compounds were experimented with in an attempt to discover possible attractive odors that might be of use in control. Eugenol, geraniol, methyl salicylate, amyl acetate, vinegar, molasses, and sugar were tried in various combinations. These were first exposed in paper plates where the insects were abundant, but no sawfly would approach them. Thick drops of the mixtures were shaken on the leaves, but these were avoided. Spraying thin solutions on the leaves was found to be the only practicable method. The above materials highly diluted with water, with water and sugar, and part of them in various combinations were experimented with. In addition sawflies were tested for their responses to water, honeydew, saliva, froth from spittle insects, crushed aphids, and cell sap from birch leaves. The sawflies avoided drops of any liquid, and would feed only on a thin film or on small droplets of solutions. They were not strongly attracted to any of the materials tested. When the leaves were dry they would feed on water and all of the watery solutions. The addition of sugar increased the attractiveness of solutions, possibly because they retained moisture longer. Saliva seemed to be rather attractive. Thin sugary solutions scented with eugenol and possibly those with geraniol gave some promise of being attractive. One tree which was sprayed with the solution containing eugenol attracted some sawflies from nearby trees, and they hovered about feeding on the sprayed leaves. In the field sawflies are often observed moving the mouthparts over the leaf surface as though feeding on honeydew or some other substance, the antennae being waved in a characteristic fashion.

NATURAL CONTROL; NATURAL CHECKS AND ENEMIES

Physical Factors

The birch leaf-mining sawfly spends about nine months of the year inside of the tough waterproof hibernaculum, where weather conditions have slight effect upon it. Drouths and early frosts have been the only important factors observed. The eggs are susceptible to drying, and drouthy conditions during the egg stage increase the percentage of eggs failing to hatch. On areas of thin soil this may be an important factor. Counts upon 2500 tagged eggs during three years show a mortality of eggs and newly hatched larvae of from 24 to 50 per cent (averaging 40 per cent) before evident feeding. The tissue immediately surrounding the egg-slit dies, turns brown, and becomes hard. Often the tip of the leaf tooth dries up, and if this extends far enough to enclose the egg the latter is killed. The sawflies, apparently recognizing the unsuit-

ability of egg-pockets, often abandon them before an egg is laid. The frail larvae which come from the eggs are very dependent upon proper conditions and easy access to food. An examination of 500 mines and egg-pockets in 1933 showed that 1.21 per cent of the larvae died without discernable feeding. If the egg-slit opens up the larva dies, or if too much tissue dies due to maceration at time of oviposition the newly-hatched larva cannot reach proper food. The effect of drouth upon both eggs and larvae is most pronounced on small birches or in sparse growth. Drouths or early frosts may cause the premature fall of the leaves and result in the death of the larvae in them, although the insects are resistant to drying and small-sized larvae resulting will often transform and produce undersized adults. Larvae in leaves which are drying up may feed until tissues become dry and hard. They tend to mine in a straight line, probably because of the greater amount of moisture away from the margin of the mine.

Prolonged soaking in low places injures some of the prepupae. The infested leaves tend to fall first and to be drifted into hollows by the wind. Water stands in some of these hollows for weeks. The hibernacula are waterproof and so resistant that the loss is small. Soaking in salt water soon kills the prepupae and destroys those washed out to sea. Material soaked in salt water for three days had over 70 per cent killed, and soaking for five days killed 98 per cent of the prepupae. This destruction of the prepupae by salt water prevents infestation of islands by ocean drift.

Fungi and Disease

Fungi apparently play a minor role in the life history of the birch leaf-mining sawfly. An *Isaria* sp. has caused trouble in the wooden breeding cages by destroying the prepupae in their hibernacula which had been cut from the leaves. In the woods occasional prepupae have been found destroyed by fungi, but most of these gave evidence of previous injury. In low wet locations molds may destroy a greater number of the prepupae. Larvae occasionally contain hard bodies or inclusions, and those which have been observed have died. The cause of these bodies is unknown.

Predators

Small mammals such as mice, and especially shrews feed upon insects to a greater or less extent in the fallen leaves. Instances have been observed where the leaves have been gnawed to pieces or where the hibernacula have been gnawed open, but examination of the leaves along the trails of these animals leads to the belief that they destroy a relatively small number of the sawflies.

Birds constitute the most important group of predators, destroying as they do large numbers of the nearly mature larvae and prepupae. Birds begin their attack on the insect about the time the larvae become half-grown. Chickadees are the most active in pecking the larvae out of their mines in the leaves. They feed both from the twigs and by nimbly swinging from the leaf-stalk with one foot, which draws the leaf closely against them. Some individuals have been watched for an hour at a time flying from one birch tree to another feeding on the sawflies. They also feed on the prepupae in the hibernacula as long as the leaves are on the trees. The large and abundant group of warblers also attacks the sawfly as long as the leaves are on the trees. Myrtle warblers have been watched on several occasions feeding on the sawfly larvae. Red-eyed vireos have been seen to extract larvae from mines, and probably other vireos feed on them. Nuthatches feed in the branches to some extent and red-breasted nuthatches appear to open a mine occasionally. The nearly mature larvae and the prepupae are attacked by goldfinches. On one big white birch, where the goldfinches congregated to feed on the seeds, most of the sawflies were destroyed. A flock was watched ripping open dozens of mines; the tearing sound could be heard for some distance. The following other species of birds have been seen to feed on the sawfly in the leaves on the trees: junco, redstart, Maryland yellowthroat, and the magnolia, black-throated green, parula, and Nashville warblers.

After the infested leaves fall to the ground other groups of birds attack the prepupae in their hibernacula. Sparrows are especially important at this time, destroying large numbers of the prepupae in some sections. Robins, juncos, fox, white-throated and song sparrows have been observed feeding on the sawfly, and freshly opened hibernacula have been found where white-crowned sparrows had fed. Areas have been examined where the fox sparrows had scratched over many patches of leaves. In such areas practically all hibernacula had been shattered by their heavy bills and the occupants eaten. Other sparrows and thrushes have been watched while feeding and are believed to destroy prepupae.

In the spring of 1929 considerable bird-work was found at two localities in southern Maine. In the fall of 1929 and since, surveys have been made of the status of the insect in Maine. Counts made on the same nineteen or twenty plots show an increasing amount of destruction by birds. Counts made in the fall of 1929 gave about 9.6 per cent destruction before the leaves fell. Counts made soon after the leaves fell attributed the destruction of over 18 per cent of the prepupae in the white birch belt to birds in 1931, over 53 per cent in 1932, about 48 per cent in 1933, over 23 per cent in 1934, and 27 per cent in 1935.

The marked drop in 1934 was apparently caused by the very unfavorable weather and a snowstorm at the time when the important groups of birds were migrating. This illustrates clearly the importance of birds at this season; the mines in the leaves are conspicuous and since the mined leaves are the first to fall the insect is exposed to the birds. Observations indicate that about one-half of the destruction which occurs on the trees takes place before the hibernacula are formed, and must be included in the bird-work. These figures for the destruction of larvae must be added to those given above for the destruction of prepupae in their hibernacula. The percentage of destruction by birds is extremely variable for different localities. In 1931 it ranged from 2 to 57 per cent, and in 1932 the range was from 20 to 85 per cent after the hibernacula were formed. This wide variation is partly due to the great range in infestation, and also because birds tend to frequent certain areas and routes. During 1932 and 1933 the estimated percentage of destruction by birds was 20% of the larvae and 50% of the prepupae after the hibernacula were formed.

A considerable percentage of the hibernacula, found to be intact at the time of the surveys in the fall, is destroyed before the sawflies emerge in June and July. A count which was made on October 13, 1932, at Bar Harbor on 523 hibernacula showed 13% of the prepupae alive. A comparable count made the same place June 12, 1933, showed 8% alive; this shows an additional mortality of 36%. On October 10, 1933, an examination of 903 hibernacula showed that 13% had been destroyed. A count was made on the same plot June 11, 1934, and 70% of 1042 hibernacula had been destroyed. Birds are believed to be important in this destruction between the time of the survey and the emergence of the sawflies, but other predators must be included. Fox sparrows have been observed feeding on the prepupae in the spring of the year and undoubtedly other ground-feeding birds do so.

Some ants destroy large numbers of sawfly larvae in the vicinity of their nests. A small amount of destruction by ants seems to be general, but mines opened by ants cannot be definitely separated from those opened by some other predators. In August, 1932, medium-sized, dull-reddish ants were found actively carrying away sawfly larvae from a group of small birches on brushy land.

Late in August, small black ants (*Formica*, *Crematogaster*, and *Dolichoderus*, determined by W. M. Mann) were found carrying away larvae of the birch leaf-mining sawfly from scrubby white and gray birches growing over partly-exposed granite. The ants concentrated upon single birches or small groups until most of the larvae had been destroyed. Eight ants were observed gnawing at or crawling around inside one mine. Some ants were observed gnawing at empty mines. Two small

white birches had 436 mines in their leaves but only twenty living sawfly larvae remained on September 14th. The nearly full-grown larvae appear to be able to ward off attacks by these small ants. A count was made on September 14th of the number of mines on twenty small trees where the ants had been seen working. The leaves on these trees contained 1407 developed mines. Larvae were present in 135 mines and absent in 1272 or 90.41%. Twelve comparable check trees had 1300 mines on them. Larvae were present in 1081 mines and absent in 219 or 16.85%. Ants also gnaw open the hibernacula and destroy the prepupae. Small dark brown and black ants proved the most serious pests in large breeding cages. Entire lots of prepupae were destroyed. Large ants were responsible for some damage in the cages. In the woods examination of the leaves indicates that ants destroy the prepupae, especially in the spring. The adult sawflies are so sluggish, when temperatures are not favorable, that ants catch them. Ants rapidly destroyed the caged sawflies in some oviposition experiments.

Parasitic Hymenoptera in their adult stage prey upon other insects. A new species of Ichneumonini was caught stinging a larva in the field. It was taken into the laboratory, where it lived for two weeks. During this time it killed and macerated large holes in three large larvae and three prepupae in order to feed on the juices. A female of *Epiurus indagator* Cress. (determined by R. A. Cushman) was caught macerating a larva of the sawfly. Other individuals of this species have been observed gnawing into mines of the sawfly. Larvae have been observed to swing the body violently about upon the approach of a parasite. A specimen of *Tenthredella bilineata* MacG. (determined by Wm. Middleton) was caught eating an adult of the birch leaf-mining sawfly.

Ground beetles or Carabidae are believed to destroy the prepupae in the fallen leaves, especially in the spring. When a number of the beetles were caged with a lot of hibernacula, they destroyed practically all of the prepupae. Hibernacula opened in the same fashion are found in the woods. Examination of thirty plots, one yard square, in mixed birch woods disclosed one to several ground beetles in nearly all cases.

Near Aurora a wireworm was found feeding upon a prepupa. Several wireworms were then collected and caged with hibernacula, which they pierced to destroy the prepupae. Dr. A. G. Böving has determined them as *Limonius* sp. and an unknown genus near *Elater*.

Larvae of lace-wing flies have been found in the field sucking the juices out of the sawfly larvae. Several were reared on sawfly larvae in the laboratory. One starved individual drove its jaws into a large larva and sucked away for over six hours, until the sawfly larva was a shrunken mass. A predacious larva (tentatively determined as a hemerobiid by A. N. Caudell) was found in a mine with a dead and shrunken sawfly larva.

Competitors

The birch leaf-mining sawfly suffers keenly in competition with the birch skeletonizer (*Bucculatrix canadensisella*). This insect has occurred in destructive numbers over large areas of Maine during the last few years. This skeletonizer appears to emerge over a longer period than the sawfly, and it develops faster and reaches larval maturity before the sawfly. Where the birch skeletonizer is heavy some of the leaves containing sawfly larvae are so completely eaten, become so dried up, or fall so early, that the sawfly larvae are unable to mature. The sawfly larvae in their later instars are highly resistant to such unfavorable conditions and many survive adverse conditions. However, an indirect effect may be still more important than the number starved. Dissection has shown that the egg-laying capacity of small individuals is only 25 per cent of that of medium-sized individuals, some being completely sterile. Numerous small and even extremely small individuals have been observed on plots where the birch skeletonizer was very heavy.

Larvae of the birch leaf-mining sawfly display irritability and intolerance of the presence of other individuals of their own kind and of other insects. Where the infestation is high, mines merge as the mined area is enlarged and larvae come into contact; this larval competition results in the loss of some larvae. Larvae will swing the body from side to side when another larva approaches. Sometimes one larva is mortally wounded by the slashing movement of the protruding jaws of another when the body is swinging about. Small larvae may be jammed into corners of the mines where they die, or both large and small larvae may be driven from a source of food or from the mine itself. The resultant loss to the species is small, because the amount of food available governs both the number which can mature and their fecundity, and because only a small percentage of the infestation ever comes into close competition.

Hornets and yellow jackets indirectly injure the sawfly to some extent by gnawing away parts of the epidermis of the leaf which enclose the mine. Earthworms have been found to destroy the prepupae in their hibernacula in an unexpected manner. The infested leaves tend to fall earliest; and therefore to lie on the surface of the ground. Earthworms pull such leaves down into their burrows and destroy them, which would result in the destruction of prepupae found in them. In one gray birch area the destruction by earthworms of prepupae was roughly estimated at 4 to 5 per cent. It has been observed only on a few low wet areas.

Parasitism

Parasites evidently hold the birch leaf-mining sawfly thoroughly in check in Europe. Throughout its wide distribution from Scotland and

Sweden to Russia and Austria no destructive outbreak has ever been reported. Its scarcity in Europe has rendered most difficult the problem of securing parasites for introduction into America. In the New World, with its natural parasites left behind in Europe, the sawfly has increased enormously. Native parasites slowly began to avail themselves of this new host, and now a series of parasites are known to attack it.

Several species of egg parasites attack the sawfly. The following species have been reared. All were determined by Mr. C. F. W. Muesebeck. *Trichogramma minuta* Riley and *Derostenus* sp. are the commonest species at Bar Harbor, and they have been bred from material collected at Great Pond. *Cirrospilus flavicinctus* Riley, *C. cinctithorax* Gir., *Cirrospilus* sp., and *Sympiesis* n. sp. have all been reared from eggs. Usually only a single parasite is found in each egg, but two are found in some eggs and occasionally three. Egg parasites were found during and since the first season's work in 1928. Some collections of eggs at Bar Harbor are rather heavily parasitized; in 1933 of one lot of forty eggs eighteen were parasitized.

The genus Cirrospilus either attacks both eggs and young larvae or the period of infestation continues into the larval state. Small mines collected in August have yielded these parasites in August and September, and mined leaves collected in October have yielded specimens in the following June and July. *Cirrospilus* sp., and *C. cinctithorax* have been reared from these mines.

The larvae are attacked by several species of parasites of the family Ichneumonidae. These Ichneumonidae have all been determined by Mr. R. A. Cushman. *Agrothereutes slossonae* Cush. is the commonest of these. It has been reared from material collected at Strong, Bryant Pond, Dallas, Freeman, West Bethel, Bowerbank, Caratunk, West Forks, Masardis, Topsfield, Danforth, Nicatous Lake, Cherryfield, Aurora, and Bar Harbor. *Epiurus indagator* Cress. has been reared from a number of localities over the state. An undescribed species of a new genus, *Alophosternum foliicola* Cush. (Cushman, 1933), has been reared from hibernacula from West Bethel, Bryant Pond, Strong, Caratunk, Bowerbank, Hartland, Eustis, Hersey, Nicatous Lake, Topsfield, Cherryfield, Aurora, and Bar Harbor. Another species of this genus, *Alophosternum* n. sp., has been taken at Bar Harbor preying upon the sawfly larvae and stinging them. Mr. Cushman thinks that it will prove to be another primary parasite. Specimens of *Spilocryptus* sp. were reared from sawfly larvae in 1928, and a number have been reared since that time from widely separated localities in the state. These parasites destroy the prepupae after the hibernacula are formed and usually overwinter in the hibernacula.

Other parasites attack the mature larvae and prepupae of the sawfly, especially the prepupae. During the summer of 1929 over one hundred specimens of *Gelis urbanus* Brues and *Gelis* sp. emerged from a large lot of infested leaves collected during the spring and early summer. Collections made since that time show that material collected in the fall after the leaves have fallen contains a low degree of parasitism by *Gelis* sps. and *Agrothereutes slossonae* and that the percentage of paratism in material collected in the late spring is far higher. A batch of hibernacula collected in June, 1934, yielded several times as many Gelis (*G. urbanus* and *G. bucculatricis*) as fall collected material from the same place. In the spring of 1935 an experimental lot of 1800 hibernacula was counted out of a large collection the remainder of which later gave an emergence of parasites of less than one-half of one per cent. The 1800 hibernacula were put in nine wire cages and placed under leaves on a mountainside from which Gelis had been secured. After remaining there from May 2 until June 10, these were brought into the laboratory. From these 1800 hibernacula one hundred and twenty-nine *Gelis urbanus* and five *Agrothereutes slossonae* emerged. The period of exposure of this material to parasitic attack was much shorter than in nature. This experiment gave additional proof that parasitism of the prepupae in the spring constitutes the most important parasitic check on the sawfly, destroying as it does the individuals, which escape other enemies, just before they mature.

The females of Gelis are unable to fly and probably attack the prepupae in their hibernacula in the fallen leaves. They are hardy active creatures and readily crawl about among the leaves. Females of *Gelis urbanus* have lived for over forty days in cages. This species has been found nearly everywhere in Maine where material has been collected, even high up on the slopes of Mt. Katahdin. *Spilocryptus* sp. and other species may attack both larvae and prepupae. A few specimens of *Opius cincticornis* Gahan have emerged, but this may not be a parasite on the sawfly. The foregoing species of parasites have all been reared from material dissected under the microscope, or from hibernacula isolated by cutting them from the leaves. Thousands of hibernacula have been cut from the leaves and caged for the parasites.

Many other species of parasites have emerged from the infested leaves. Most of these have been recorded only as dipterous or lepidopterous parasites. Part of them will be found to be parasites on the sawfly. Two or more specimens of all of the following have emerged, most of them from hibernacula cut out of the leaves: *Rhoptromeris* sp. (determined by A. B. Gahan), *Cratospila* sp., *Bucculatriplex secundus* Vier., *Ashmeadopria* sp., *Aspilota* sp., *Oncophanes betulae* Mues. *Spano-*

merus sp., *Xenotoma* sp., *Sympiesis* n. sp., *Epirhyssalus* sp., and *Mesochorus* n. sp. (determination by C. F. W. Muesebeck and R. A. Cushman).

The only parasites of the adults which have been observed are red spiders. At Caratunk in 1931 sawflies were seen with red spiders attached to their back.

Parasitism has been found to vary widely in one section. In one locality several hundred hibernacula were examined without a parasite being evident, but one-half mile down the mountainside a tree was found with 27.9 per cent of its 337 prepupae parasitized. The parasites tend to be grouped into egg parasites during June and July; larval parasites during July, August, and September; and prepupal parasites during the winter and spring. Egg parasitism has ranged from 21 to 25 per cent in the counts made at Bar Harbor and Great Pond. Strong, Nicatous Lake, Aurora, and Bar Harbor have had the highest parasitism. At Bar Harbor in 1932 the parasitism in counts of larvae and prepupae ranged from 5.5 to 27.9 per cent which is the highest found to date. Collections of prepupae made in the spring of 1934 and 1935 indicate that prepupal parasites are increasing in importance.

APPLIED METHODS OF CONTROL

Control by Forest Management

A study of injury caused by the birch leaf-mining sawfly under various types of mixture, density, and exposure has shown that the damage varies very little with these factors. However, other studies made by the Maine Forest Service in connection with insect control, indicate very strongly that birch stands should be kept reasonably dense. Clear cutting of stands rather than diameter limit cutting is advised, as a general practice in preventing damage from insects and diseases attacking birch.

Biological Control

While the white birch belt contains the most valuable commercial stands, birches are found throughout Maine. Over this great area direct control measures are impractical; control must come through the increased efficiency of the natural enemies now present, through introduction of foreign enemies, or through a combination of both. Native parasite liberations were begun in 1931 when parasites were liberated at Caratunk, Princeton, Cherryfield, and Great Pond. In 1932 parasites were liberated at Aurora, Dallas, Cherryfield, Hersey, Lincoln, and Bar Harbor. In 1933 liberations of parasites were made at Aurora, Cherryfield, Caratunk, Lincoln, Princeton, and Bowerbank. In 1934 parasites

were liberated at Nicatous Lake, Jim Pond, and Bar Harbor. In 1935 liberations were made at Lakeville, Jim Pond, and Dallas Plantation. Large collections of material are in the breeding cages at present, and parasite breeding and liberation work is being continued.

Efforts have been made to secure the introduction of foreign parasites ever since the sawfly became so destructive in Maine. The scarcity of the sawfly in Europe has made such work difficult, but that fact indicates that parasites which habitually attack the sawfly will hold it in check. Through the establishment of these in America the sawfly should cease to be an important problem. The most promising parasites have been found in Austria. Some of these have been brought to America by entomologists of the United States Bureau of Entomology. *Tranosema pedella* Holmgren was liberated at North Conway, New Hampshire, in 1931. If this species establishes itself, it will probably soon spread into Maine. A solitary species of Chrysocharis was liberated in 1931 at Strong and a gregarious species of Chrysocharis there in 1933. The solitary species of Chrysocharis and *Phanomeris phyllotomae* were liberated at Bethel during 1933. In June, 1933, in coöperation with the Gypsy Moth Laboratory a parasite liberation plot was established near Bar Harbor in an area where both this sawfly and *Fenusa pumila* are abundant. Colonies of two species of Chrysocharis were liberated June 7. A large lot of *Phanomeris* sp. was liberated July 8, and a shipment of *Phanomeris phyllotomae* July 27.

Dusts and Poisons for the Adult

The possibility of destroying the emerging sawflies with materials applied to the leaves on the ground was the object of some experiments in 1929 and 1930. Leaves containing hibernacula were dusted just before the period of emergence. The following were used: calcium arsenate, dry lime sulphur, and lead arsenate. These dusts killed only the sawflies which became heavily dusted while they were emerging. A thin honey-water solution was poisoned with sodium arsenite and sprayed over leaves from which the sawflies were emerging. Some of the sawflies emerging at the time fed on the mixture and were killed, but they fed only during the short time before the spray dried up.

Control on Ornamental Trees
Bordeaux Mixture as a Repellent

The value of Bordeaux as a repellent, used at the rate of four ounces of dry Bordeaux per gallon of water, has been given three trials. The counts were made over a month later. All applications were made with a five-gallon hand pump. From a spray applied June 13, 1929, the following results were secured on fifteen small white birches: 822 or 3.7 per cent of the 21,799 leaves became infested; on the fifteen check

trees 1504 or 16.7 per cent of the 8980 leaves became infested; therefore the reduction in infestation was from 16.7 per cent to 3.7 per cent or about 78 per cent. June 3, 1930, ten trees were sprayed with Bordeaux, and on June 17 five of these were given a second application. On the trees which were sprayed once, 41 of the 1972 leaves or 2.1 per cent became infested. The twice-sprayed trees had 27 of 2206 leaves infested or 1.2 per cent. The five check trees had 113 of 1331 leaves infested, or 8.5 per cent. These figures show a reduction in infestation of 78 per cent for one application of Bordeaux, and 86 per cent for two applications.

Two adjacent white birches were selected on June 22, 1932; one of these was sprayed with Bordeaux, and a cage was placed over both. Hundreds of sawflies were introduced for several days, all living sawflies being removed at the end of a nine-day period. Samples of one hundred leaves from each tree were examined under the microscope and the eggs counted. The unsprayed lot of leaves contained 479 eggs, while the sprayed lot of leaves contained 78 eggs, a reduction of 83.9 per cent. Later all of the leaves on both trees were counted for percentages of infestation, and the sprayed tree was found to have a reduction in leaves infested of 84 per cent compared with the unsprayed tree. A considerable percentage of the leaves on a young tree are unsuitable for oviposition; suitable leaves on the unsprayed tree were filled with eggs. This experiment shows clearly that even when under stress because of lack of suitable leaves for oviposition leaves sprayed with Bordeaux are strongly avoided. Likewise, in the field the sawflies avoid diseased, honey-dew covered, and otherwise unsatisfactory leaves when ovipositing.

Nicotine Sulphate

A nicotine sulphate spray will control the birch leaf-mining sawfly if spraying is done before the mines exceed one-fourth inch in diameter. Despite the fact that the eggs and larvae are enclosed within the leaf, 100 per cent kill may be secured by proper spraying. During 1928 (Peirson, 1929) a kill of 98 to 100 per cent was secured with nicotine sulphate 1-400 plus 1 oz. of dissolved laundry soap per gallon of spray. On July 23, 1929, nicotine sulphate, 1-400, with soap was applied to eleven small white and gray birch trees. Counts over a month later showed a kill of 98.9 to 100 per cent. In 1930 a series of the nicotine sprays was applied. Dilutions of 1-400, 1-600, 1-800, and 1-1000 were used, with enough soap added to make a light suds. These dilutions all gave 100 per cent kill.

During 1931 and 1932 nicotine sprays were repeated on a larger scale, with weaker dilutions added. With all, enough soap was added to make a light suds. The sprays were applied with a five-gallon hand pump, and on very favorable days. The results are shown in Tables 5

TABLE 5

Nicotine Sulphate Sprays against the Birch Leaf-Mining Sawfly at Great Pond, Maine, July 21, 1931

Spray	Dilution	No. Trees	Infestation	No. Larvae	% Dead	Kind of Tree
N. S. plus Penetrol . . . 1-200	1-1500	5	Heavy	All trees closely examined; no living larvae found	100	White Birch
N. S. plus Soap	1-600	7	"		"	" "
"	1-800	6	"		"	" "
"	1-1000	9	"		"	" "
"	1-1500	6	"		"	" "
"	1-2000	6	"		"	" "
	Check	4	"	400	34.75	" "

TABLE 6

Sprays against the Birch Leaf-Mining Sawfly at Bar Harbor, Maine, July 25, 1932

Spray	Dilution	No. Larvae Counted	No. Dead	No. Alive	% Dead	Kind of Tree
Red Arrow	1-200	1000	783	217	78.3	Gray Birch
" "	1-400	1000	719	281	71.9	" "
" "	1-600	1000	252	748	25.2	" "
" "	1-800	810	159	651	19.6	" "
" "	1-1000	1000	185	815	18.5	" "
	Check	1000	149	851	14.9	" "
Nicotine Sulphate . . .	1-1000	1000	1000	0	100.0	" "
Plus Soap	1-1500	1000	993	7	99.3	" "
"	1-2000	1000	991	9	99.1	" "
"	1-2500	1000	986	14	98.6	" "
"	1-3000	1000	820	180	82.0	" "
	Check	1000	149	851	14.9	" "
Nicotine Sulphate . . .	1-1000	1000	999	1	99.9	White Birch
Plus Penetrol	1-1500	1000	988	12	98.8	" "
1-200	1-2000	1000	952	48	95.2	" "
"	1-2500	1000	825	175	82.5	" "
"	1-3000	1000	748	252	74.8	" "
	Check	1000	139	861	13.9	" "

and 6. The actual kill was greater than the counts show because the eggs which had not hatched when the sprays were applied were killed, and most of these were not evident at the time the counts were made over a month later. These experiments show that the stronger dilutions of nicotine sulphate are highly effective against the sawfly. A series of Red Arrow sprays was also applied in 1932.

The larvae of the birch leaf-mining sawfly become highly resistant to nicotine sprays as they mature. Experiments in 1929 and 1931 gave a progressively heavy decrease in the percentage of kill after the larvae passed the second instar. The kill from the spray is unsatisfactory after the third instar is reached. The value of nicotine sulphate 1-800 has been shown in results secured by commercial spray men. Several large-scale spraying operations have been conducted on Mt. Desert Island estates, and a satisfactory degree of control secured on large trees by the use of suitable equipment.

RECOMMENDATIONS FOR CONTROL

The predatory enemies of the birch leaf-mining sawfly should be protected. The birds are the most important of these. Native parasites are attacking the sawfly in increasing numbers, and these are doubly valuable because they normally attack native insects. These are in need of further study. Predators are valuable, but parasitic insects having the power to increase as fast or faster than their host and increasing only by destruction of their host are needed to control pests like this sawfly. The parasites which normally attack this sawfly, but which were left behind in Europe when the sawfly was brought to America, are the best hope for successful biological control. Continued coöperation with the Federal Bureau of Entomology in the work of breeding and establishing the most important foreign parasites is desirable.

On ornamental trees a high degree of control can be secured by a single, thorough application of nicotine sulphate at the rate of one part to eight hundred parts of water. The addition of enough dissolved soap to make a light suds of the water improves the spray. Spraying should be done on warm days; but a slight amount of water scald has been seen in a few instances on white birch sprayed during the middle of hot, sultry days. Experimental work has given a high degree of control with dilutions of 1-1000 and 1-1500, but these have not been tested on a large scale with power outfits. The time to apply this spray varies somewhat with the season and the locality. The spray should be applied after all or practically all of the eggs have been deposited, and before many of the oldest mines exceed one-fourth inch in diameter. A good kill has been secured until the oldest mines exceed one-half inch in

diameter, after which the value of the spray rapidly decreases. The proper date is about July 18 to 25 at Bar Harbor, and this period will apply to southern Maine. In the northern localities it will be a little later.

Bordeaux mixture applied as a repellent is very effective in preventing an infestation. The first application should be applied about June 10-15 in central Maine just as the adults begin to appear. A second application should be made two weeks later.

SUMMARY

The birch leaf-mining sawfly became epidemic in Maine in 1927. A native of Europe, it invaded Maine through New Brunswick from Nova Scotia. By 1928 the growth of birch was greatly reduced. Birch throughout Maine has been injured and the insect has spread westward into New York. Plots were established throughout the birch belt and studies have been made annually on the percentages of infestation and retardation in growth. The average annual loss in growth has been about 20% since 1927, and in addition the birch mills have found that the quality of the wood has been injured. Infestation has been decreasing during recent years in eastern Maine and the birch is slowly recovering its normal growth. Infestation and injury remain high in the western portion of the state.

White and gray birch are favored foods but all species of birch except black are attacked. Eggs are laid in the leaf-teeth in June and July and hatch in nineteen days. The larvae mine in the leaves and mature in about fifty-seven days. Each larva consumes about 40% of a leaf. A hibernaculum is formed in late summer or fall by the prepupa in the leaf where the insect remains until the adult emerges the next June or July.

Predators of many species and orders have been found destroying the sawflies. Warblers, vireos, sparrows, and chickadees have been the most important. Ants, some parasitic Hymenoptera, Carabidae, shrews, mice, and larvae of Neuroptera prey on the sawfly. Parasites attack all stages. Prepupal parasites are most important. Large quantities of material have been collected in order to rear parasites. Parasites have been liberated at many points in the state. Foreign parasites have been brought in through coöperation with the United States Bureau of Entomology. Liberations of several species have been made in different parts of Maine.

Several sprays have been tested. Nicotine sulphate 1-800 with soap or Penetrol has given 95-100% kill when applied before the mines exceeded one-fourth inch in diameter. The proper time to spray in central Maine is between July 18 and July 25.

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